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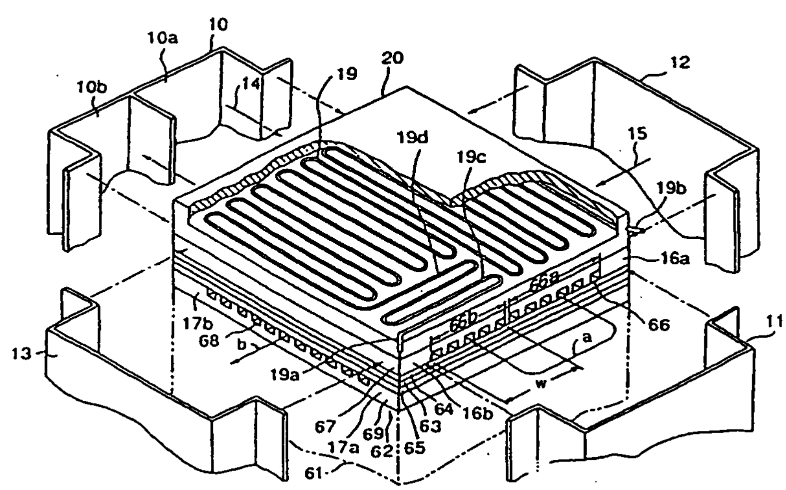

(57) Abstract

Disclosed is a fuel cell assembly in which the electrolyte and other reactants having evaporated into the fuel gas or oxidizing gas streams passing through the cells can be condensed and recovered back into the cells. This comprises a stack (1) of a plurality of fuel cells (2), each cell (2) having a pair of porous electrodes (4, 5) with an electrolyte layer (3) being sandwiched therebetween and a pair of gas guide means (7, 9) as disposed adjacent to and over said pair of porous electrodes (4, 5) for passing fuel gas (14) and oxidizing gas (15) therethrough in a direction perpendicular to each other, and a cooling means (19, 20) for cooling a part of a nongenerating zone being positioned outside the generating zone to be defined by the range of said pair of gas guide means (7, 9) overlapping with each other in the stacking direction for thereby condensing and recovering the condensable substance from the gases being guided by the gas guide means into the cells (2). The stack realizes prolongation of the operable life of the cells and increase in the power–generating efficiency of the cells.

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Description

A Cooling Plate For a Fuel Cell Stack Assembly

Technical Field

The present invention relates generally to a fuel cell, and, more particularly to the recovery of a liquid electrolyte, which has evaporated into the reactant gas streams passing through a fuel cell stack during operation. The evaporated electrolyte is internally recovered and returned to the cells.

Background Art

As is well known, a fuel cell is a device for directly converting into electric energy the Gibbs free energy portion of the difference between the chemical potential which the fuel gas and oxidizing gas have and the chemical potential which the reaction product of the two has.

The basic fuel cell comprises a non-conductive layer impregnated with an electrolyte, for example, silicon carbide impregnated with phosphoric acid sandwiched between a pair of porous electrodes (anode and cathode), in which a fuel gas and oxidizing gas are supplied to the electrodes to generate electric power through an electrochemical reaction between the two generating electrolytic ions and electrons. The electric power is taken out of the cells by way of an external load circuit through which the electrodes flow to the cathode where they react with the oxidant gas and the electrolytic ions.

However, the electric power generated by an individual cell is about 1 V. To construct a high-power generating system individual planar cells are stacked in series to form a fuel cell stack by which the overall electric power generated may be equal to the sum total of the electric power generated by all the constituent cells.

The fuel cell stack of this type is provided with manifolds or the like for supply and discharge of reactant fuel gas and oxidizing gas to and from each cell. The operation of fuel cells produces electric power, heat and water. In order to remove the heat, thereby ensuring the electric power-generating capacity of each cell and its proper temperature control, the cell stack is provided with cooling plates

at various cell intervals each having an in-plane coolant flow means, to which, for example, water is supplied as the coolant.

A fuel cell stack using, for example, phosphoric acid as the electrolyte is generally operated at about 200°C. The saturated vapor pressure of phosphoric acid at the operating temperature is on the order of 1 ppm or lower in terms of the concentration of its component, phosphorus pentoxide (P_4O_{10}). However, over an estimated operating period of tens of thousands of hours, the amount of phosphoric acid having evaporated into the fuel gas and the oxidizing gas to be directly discharged outside the cell stack is not negligible. In operation of a fuel cell it is critical that a proper amount of electrolyte, e.g. phosphoric acid, be maintained to prevent mixing of reactants.

One approach to maintain electrolyte was to reduce the temperature of a part of the power-generating zone of fuel cells to thereby condense the electrolyte having evaporated into the fuel gas or the oxidizing gas and recover and return it into the fuel cells.

For example, U.S. Patent 4,414,291 suggests a method of condensing the electrolyte having evaporated into fuel gas or oxidizing gas and recover and return it into fuel cells, which comprises providing a nongenerating zone not carrying a catalyst in a part of the generating zone adjacent to the gas outlet side of the cell and cooling the nongenerating zone, whereby the electrolyte is condensed in the thus-cooled, nongenerating zone. The prior art also suggests another electrolyte-condensing method for fuel cells, in which, however, is provided a nongenerating zone of an insulating sheet as inserted between the electrolyte layer and each electrode in a part of the generating zone adjacent to the gas outlet side of the cell, and the electrolyte having evaporated into fuel gas or oxidizing gas is condensed in the cooled, nongenerating zone and recovered and returned into the cell.

However, such prior art systems are problematic in that the nongenerating zone to be the electrolyte-condensing zone is formed at the sacrifice of a part of the generating zone, resulting in the reduction in the effective generating zone which lowers the generating capacity of the fuel cell stack.

In those prior art systems, the electrolyte-condensing zone is provided adjacent to the gas outlet portion. The amount of the electrolyte existing in the gas around the gas outlet portion is influenced by the temperature gradient throughout the gas-passing zone to the outlet and therefore may not always reach the

saturated vapor pressure thereof. This results in a limited condensation rate of the electrolyte from the gas into the constituent parts of the cell. Therefore, exhaust gas of which the electrolyte content is in a super-saturated condition relative to the outlet temperature would be discharged out of the fuel cell stack. In order to ensure electrolyte recovery a large reduction in the outlet temperature is needed, which, however, is further problematic in that it results in the reduction in the voltage of the cell which then results in the reduction of the generating capacity of the cell stack.

It is therefore highly desirable to produce a fuel cell stack that can recover electrolyte evaporated into the fuel gas or the oxidizing gas and return it to the cells without reducing the effective generating zone.

Disclosure of Invention

The invention provides a fuel cell stack, which comprises a stack of a plurality of fuel cells, each cell having a pair of porous electrodes with an electrolyte layer being sandwiched therebetween and a pair of gas guide means disposed adjacent to said pair of porous electrodes for passing fuel gas and oxidizing gas therethrough in a direction perpendicular to each other, and a cooling means for a group of cells for cooling a part of a nongenerating (nonelectrochemical reaction) zone being positioned outside the generating (electrochemical reaction) zone to be defined by the range of said pair of gas guide means overlapping with each other in the stacking direction to thereby keep the temperature of said part of the nongenerating zone portion lower than that of said generating zone thereby condensing and recovering at least a part of the condensable substance from the gases being guided by the gas guide means into the cells.

In the fuel cell stack, the cooling means may be to cool the portion nearer to the gas outlet portion of at least one gas guide means within the nongenerating zone to thereby make the nearer portion have the defined lower temperature.

In an alternative embodiment, a fuel cell stack comprises a stack of a plurality of fuel cells, each cell having a pair of porous electrodes with an electrolyte layer being sandwiched therebetween and a pair of gas guide means disposed adjacent to said pair of porous electrodes for passing fuel gas and oxidizing gas therethrough in a direction perpendicular to each other, at least one gas guide means being so constructed as to have at least two or more groups of forward and

backward channel loops directed to the opposite sides, through which said gas travels forward along said porous electrodes and then backward along them, and a cooling means for each group of cells for cooling at least the gas inlet portion of said backward channel loops of said gas guide means within a nongenerating zone being positioned outside the generating zone to be defined by the range of said pair of gas guide means overlapping with each other in the stacking direction to thereby keep the temperature of said gas inlet portion lower than that of said forward channel block in said generating zone, thereby condensing and recovering at least a part of the condensable substance from the gases being guided by the gas guide means into the cells.

In one preferred embodiment of the fuel cell stack, the cooling means is provided with a cooling plate having a coolant channel inside it, through which a coolant is passed, and is disposed inside the stack. More preferably, in this case, the cooling plate is to produce the defined lower-temperature portion in each cell by selection of the arrangement of the coolant and the channel flow direction of the coolant.

In the fuel cell stack of the invention, the condensable substance is electrolyte vapor in the reactant gas streams for the fuel cells using a liquid electrolyte, while it is water vapor for the fuel cells using a solid polymer electrolyte.

Accordingly, it is a general object of the present invention to provide a cell stack that overcomes difficulties of prior art fuel cell stacks. It is a more specific object of the present invention to provide the nongenerating zone of a fuel cell stack with cooling means to lower the temperature of the nongenerating zone below the temperature of the generating zone, thereby condensing and recovering the condensable substance, for example, the electrolyte from the gas being guided by the gas guide means into the cells.

It is yet another object of the present invention to provide the condensation and recovery of the condensable substance from gases into the cells without sacrificing the intrinsic generating zone and therefore without reducing the power-generating efficiency of the fuel cell stack.

It is still a further object of the present invention to provide the condensation and recovery zone which is positioned halfway through at least one gas guide means. In one embodiment of at least one gas guide means having a forward and backward gas-traveling structure through which gas travels first forward along the

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porous electrodes and then returned backward in the direction opposite to the forward-traveling direction, the condensation and recovery zone is disposed in the backward-traveling gas inlet portion within the nongenerating zone. In this embodiment having the thus-positioned condensation and recovery zone, the high-temperature gas having traveled through the forward-traveling channels is condensed in the cooled backward-traveling channels. In this, therefore, the temperature reduction in the condensation and recovery zone is great. Accordingly, this ensures an increased degree of effective condensation of electrolyte or water vapor without excessive cooling of the condensation and recovery zone. In addition, since the cooling zone for condensation and recovery of electrolyte or water vapor can be concentrated in a limited area, the reduction in the power-generating capacity of the fuel cell stack is minimized for effective condensation and recovery of electrolyte or water vapor.

These and other objects and advantages of the present invention will become more readily apparent when the following description is read in conjunction with the accompanying drawings.

Brief Description of Drawings

Fig. 1 is a partial-exploded perspective view of the first embodiment of a fuel cell stack of the invention.

Fig. 2 is a plan view of the coolant plate of the stack of Fig. 1.

Fig. 3 is a graphical view illustrating the gradient of the evaporation and condensation rates of the electrolyte in the stack of Fig. 1.

Fig. 4 is a graph indicating the comparison between the stack of Fig. 1 and a conventional fuel cell stack with respect to the time-dependent electrolyte recovery in the two.

Fig. 5 is a plan view of a coolant plate of another embodiment of the fuel cell stack of the present invention.

Fig. 6 is a plan view of a coolant plate of yet another embodiment of the fuel cell stack of the present invention.

Fig. 7 is a plan view of a coolant plate of still another embodiment of the fuel cell stack of the present invention.

Fig. 8 is a plan view of a coolant plate of still yet another embodiment of the fuel cell stack of the present invention.

Fig. 9 is a plan view of a coolant plate of a further embodiment of the fuel cell stack of the present invention.

Fig. 10 is a plan view of a coolant plate of yet a further embodiment of the fuel cell stack of the present invention.

Fig. 11 is a plan view of a coolant plate of still a further embodiment of the fuel cell stack of the present invention.

Fig. 12 is a plan view of a coolant plate of still yet a further embodiment of the fuel cell of the present invention.

Fig. 13 is a vertical cross-section of a fuel cell with fuel plate and oxidizing plate coolant channels.

Best Mode for Carrying Out the Invention

Now, referring to the drawings in detail the liquid electrolyte recovery means of the preferred embodiments is shown.

As best seen in Fig. 1, a fuel cell stack 61 is composed of from several tens to several hundreds of fuel cells 62.

The fuel cell 62 includes an electrolyte layer 63; an anode 64 and a cathode 65 both of an electroconductive porous material, which are formed to have the same peripheral size as the electrolyte layer 63 and disposed to sandwich the electrolyte layer 63 therebetween; a fuel gas guide plate 67 of an electroconductive porous material, which is formed to have the same peripheral size as the anode 64 and to have, in its surface facing the anode 64, a plurality of parallel fuel gas guide channels 66 for supplying fuel gas passing therethrough to the anode 64; and an oxidizing gas guide plate 69 of an electroconductive porous material, which is formed to have the same peripheral size as the cathode 65 and to have, in its surface facing the cathode 65, a plurality of parallel oxidizing gas guide channels 68 for supplying oxidizing gas passing therethrough to the cathode 65, the oxidizing gas guide channels 68 being perpendicular to the fuel gas guide channels 66. Each electrode may be integrated with the corresponding gas guide plate, as shown in U.S. Patent 4,279,970 or alternatively, each gas guide plate may be so formed as to have fuel gas guide channels in one surface and oxidizing gas guide channels in the other surface perpendicular to each other as shown in U.S. Patent 4,157,327.

The peripheral side surfaces of the stack 61 each are provided with fuel gas manifolds 10, 11 and oxidizing gas manifolds 12, 13, respectively, for supplying and removing fuel gas and oxidizing gas to the fuel gas guide channels 66 and the oxidizing gas guide channels 68 of the cell 62.

In this preferred embodiment, fuel gas 14 is supplied to the forward channels 66a of the fuel gas guide plate 67 of the cell 62 by the action of the portion 10a of the fuel gas manifold 10 as shown by arrow "a", then reversed or turned backward at the fuel gas manifold 11, then supplied to the backward channels 66b of the guide plate 67, and finally discharged outside the stack 61 via the portion 10b of the manifold 10. In this preferred embodiment, oxidizing gas 15 is supplied to the oxidizing gas guide channels 68 of the cell 62 by the action of the oxidizing gas manifold 12 as shown by arrow "b", and then discharged outside the stack 61 via the oxidizing gas manifold 13.

In this embodiment, the electrolyte, e.g. phosphoric acid, is sorbed into and held by the electrolyte layer 63, the anode 64, the cathode 65, the fuel gas guide plate 67 and the oxidizing gas guide plate 69.

The fuel gas guide plate 67 is so formed as to have end portions 16a, 16b at its sides adjacent to the outermost fuel gas guide channels 66, which are well known edge seals which are also impregnated with phosphoric acid, and the fuel gas traveling through the fuel gas guide channels 66 is prevented from leaking out into the oxidizing gas manifold 12 or 13 by the phosphoric acid in the end portions 16a and 16b. Similarly, the oxidizing gas guide plate 69 is so formed as to have end portions 17a, 17b at its sides adjacent to the outermost oxidizing gas guide channels 68, which are well known edge seals which are also impregnated with phosphoric acid, and the oxidizing gas that is traveling through the channels 68 is prevented from leaking out into the fuel gas manifold 10 or 11 by the phosphoric acid in the end portions 17a and 17b.

As is shown in the illustrated fuel cell stack 61, the portion of the electrolyte layer 63 just below the end portions 16a, 16b in the periphery of the electrolyte layer 63 overlaps with the oxidizing gas guide channels 68. Similarly, the portion of the electrolyte layer 63 just above the end portions 17a, 17b in the periphery of the electrolyte layer 63 overlaps with the fuel gas guide channels 66. Accordingly, the peripheral portion of the fuel cell 62 comprising the end portions 16a, 16b, 17a, 17b is a non-power generating zone, while the inner portion of the fuel cell 62

comprising that portion of the fuel gas guide channels 66 that overlaps with that of the oxidizing gas guide channels 68 in the stacking direction is a power-generating zone.

During operation, the cell 62 generates electric power, heat and water. Therefore, the stack 61 must be cooled to remove this heat, thereby maintaining the temperature of the cell 62 below the heat-resisting temperature of the constituent parts, at which the electric power-generating capability of the stack 61 is optimized, for example, to about 200°C and maintaining this temperature, while removing the generated heat from the cell stack 61 to utilize it for any other purpose.

In this preferred embodiment, a cooling plate 20 is interposed between each cell stack block of a plurality of fuel cells 62, the plate 20 having a coolant pipeline or coolant channel 19 disposed therein. In this coolant channel 19 a fluid, e.g., water, is used as the coolant, and the cooling water is supplied through the coolant inlet 19a and discharged via the coolant outlet 19b. The temperature and the pressure of the cooling water are so controlled that the cooling water is in a single-phase liquid condition at the inlet 19a, then is boiled in the channel 19, and is finally in a vapor-liquid two-phase condition at the outlet 19b.

This embodiment is characterized by the flow arrangement of the coolant channel 19, which is illustrated in Fig. 2. In Fig. 2, the flow arrangement of the channel 19 in the cooling plate 20 as interposed in the stack 61 is drawn to overlie the fuel gas stream 14 and the oxidizing gas stream 15 both passing through the fuel cell 62, and the end portions 16a, 16b at the sides adjacent to the outermost fuel gas guide channels 66 and the end portions 17a, 17b at the sides adjacent to the outermost oxidizing gas guide channels 68.

Generally in a fuel cell stack such as that illustrated herein, the electrochemical cell reaction is more active in the inlet portion for both the fuel gas 14 and the oxidizing gas 15, and this results in a larger quantity of heat generated in that portion. Also in the stack 61 of the preferred embodiment, a larger quantity of heat is generated in the portion of the forward channels 66a of the fuel gas guide plate, which corresponds in the inlet portion for both the fuel gas 14 and the oxidizing gas 15, resulting in a higher temperature in that portion. In contrast to this, the temperature of the portion of the backward channels 66b is lower, as the

concentration of hydrogen in the fuel gas and oxygen in the oxidizing gas in that portion are lower resulting in less heat generation.

Therefore, in this preferred embodiment, the coolant channel 19 is so arranged that the channel part 19c downstream of the coolant inlet part 19a, at which the temperature of the cooling water being introduced into the coolant channel 19 is the lowest, is positioned adjacent to the inlet portion of the backward channels 66b of the fuel gas guide plate and over the end portion 17a, and that the channel part 19d downstream of the channel part 19c is positioned in a serpentine manner to be generally the same width as that of the width of the portion of the backward channels 66b, and that the part further downstream of this serpentine channel part is positioned to be above the end portion 16b, and thereafter to be positioned at a predetermined pitch toward the coolant outlet 19b.

Having this coolant-channel arrangement, the fuel cell 62 is cooled most effectively around the inlet portion of the backward channels 66b for the fuel gas stream within the nongenerating zone of the portion overlapping with the end portion 17a, hence that part of the fuel cell 62 shall have the lowest temperature. In the illustrated preferred embodiment, one cooling plate 20 per fuel cell stack block of a plurality of fuel cells 62 is interposed in the cell stack 61, in which the temperature gradient in each fuel cell 62 is analogous to each other.

The fuel gas upstream of the backward channels 66b contains vapor of the electrolyte, phosphoric acid, which evaporated from the fuel cell 62 while traveling through the forward channels 66a at higher temperatures. The phosphoric acid vapor is rapidly cooled in the inlet portion of the backward channels 66b and kept at a lower temperature, and is thus condensed at an extremely high rate into liquid which adheres around the inlet portion of the backward channels 66b. The condensed phosphoric acid is then recovered.

The temperature change in the fuel gas traveling from the forward channels 66a to the inlet portion of the backward channels 66b is rapid from a higher-temperature level to a lower-temperature level. This rapid temperature change ensures the large condensation rate of the electrolyte. The phosphoric acid having been condensed around the inlet portion of the fuel gas backward channels 66b is recovered through the porous parts of the fuel cell 62 and returns back to the fuel gas forward channels 66a, by wicking in which the amount of phosphoric acid has been reduced by vaporization.

In the fuel cell stack of the present invention, the vaporization and the condensation of the electrolyte in the stack and also the movement of the liquid-phase phosphoric acid in the fuel cell were evaluated to obtain data on the movement, evaporation and recovery of the acid.

Fig. 3 is a gradient map illustrating the evaporation rate gradient (70) and the condensation rate gradient (71) (mol/sec/cm^2) of phosphoric acid having evaporated from the cell to the fuel gas and having condensed from the fuel gas back to the cell during operation. As can be seen in the evaporation/condensation map, the condensation rate of phosphoric acid is greatest at the center of the gradient (72) which is at the inlet portion of the fuel gas backward channels 66b where the phosphoric acid is recovered in that inlet portion.

As can be further seen in Fig. 3, after the fuel gas flows through the phosphoric acid condensation zone set around the inlet portion of the fuel gas backward channels 66b, the fuel gas further travels toward the outlet portion of the backward channels 66b. Thus, the arrangement of the condensation zone is effective in reducing the phosphoric acid loss by evaporation.

Fig. 4 is a graph indicating the comparison between two similar fuel cells (A) and (B) both having the same temperature gradient, with respect to the time-dependent phosphoric acid remainder in the two. The cell (A) has a portion for condensing and recovering phosphoric acid around the fuel gas guide channels and around the oxidizing gas guide channels as taught by the present invention, while the cell (B) does not.

As is seen from Fig. 4, the time-dependent phosphoric acid loss from the cell (A), having a portion for condensing and recovering phosphoric acid, is smaller than that from the cell (B) not having it, which would indicate that the durable life of the cell stack (A), which depends on the phosphoric acid loss therefrom, is longer than that of the cell stack (B).

In the fuel cell stack of the present invention, the nongenerating zone found in prior art cell stacks is replaced by end portion edge seals which are used as the phosphoric acid condensation and recovery zone. Therefore, since the cell stack of the present invention does not require any additional, nongenerating zone, effective condensation and recovery of phosphoric acid is attained therein without sacrificing the power-generating capacity of the generating zone of the stack, and the operable life of the stack can be prolonged. In particular, in the stack of the

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illustrated embodiment where only the narrow nongenerating zone, consisting of the end portion edge seals, including the portion around the fuel gas guide channels and that around the oxidizing gas guide channels is cooled to form a lower-temperature zone for condensing and recovering phosphoric acid, the power-generating zone of each cell is not reduced so that the maximum possible current density of each cell relative to the applied load current is not reduced. Accordingly, the in-plane axial load distribution in each cell will prevent the cell from being damaged by the load concentration in a limited local area of the cell. Thus, the coolant channel arrangement in the preferred embodiment is effective in prolonging the life of the fuel cell stack.

Fig. 5 is a plan view illustrating another preferred embodiment of a fuel cell of the fuel cell stack of the invention.

One difference between the embodiment of Fig. 5 and that of Fig. 1 is in the arrangement of the coolant channel 21 in the cooling plate 20a.

The coolant channel 21 is so arranged that the part 21c downstream of the coolant inlet part 21a, at which the temperature of the cooling water being introduced into the coolant channel 21 is the lowest, is positioned in the outlet portion of the oxidizing gas guide channels 68 and over the end portions 16b, that the coolant channel part 21d downstream of the part 21c is positioned in a serpentine manner to be generally the same width as that of the width (w) of the portion of the fuel gas backward channels 66b and over the end portion 17a, and that the part further downstream of this serpentine channel part is positioned to be above the end portion 16b, and thereafter to be positioned at a predetermined pitch toward the coolant outlet 21b.

Having this coolant-channel arrangement, the fuel cell 62 is cooled effectively around the outlet portion of the oxidizing gas guide channels 68, or in the portion overlapping with the end portion 16b and in the inlet portion of the backward channels 66b for the fuel gas stream, hence those portions of the cell shall have a lower temperature. Accordingly, the vapor of the electrolyte, having evaporated from the fuel cell 62 into the fuel gas and into the oxidizing gas while the gases are traveling through or below the forward channels 66a having a higher temperature is rapidly cooled in the inlet portion of the backward channels 66b and in the outlet portion of the oxidizing gas guide channels, the both portions having been cooled to have a lower temperature, and thus electrolyte is condensed at an

extremely high rate into liquid drops in those portions. The thus-condensed phosphoric acid drops are then recovered.

Fig. 6 is a plan view illustrating yet another preferred embodiment of a fuel cell of the fuel cell stack of the invention.

One difference between the embodiment of Fig. 6 and that of Fig. 1 is in the piping arrangement of the coolant channel 22 in the cooling plate 20b.

The coolant channel 22 is so arranged that the part 22c downstream of the coolant inlet part 22a, at which the temperature of the cooling water being introduced into the coolant channel 22 is the lowest, is positioned in the outlet portion of the oxidizing gas guide channels 68 and over the end portion 16b, that the coolant channel part 22d downstream of the part 22c is positioned in a serpentine manner to be generally the same width as that of the width (w) of the portion of the fuel gas backward channels 66b and over the end portion 17b, and that the part further downstream of this serpentine channel part is positioned to be above the end portion 16b in the stacking direction, and thereafter to be positioned at a predetermined pitch toward the coolant outlet 22b.

Having this coolant channel arrangement, the fuel cell is cooled effectively around the outlet portion of the oxidizing gas guide channels 68, or, in the portion overlapping with the end portion 16b in the stacking direction and in the outlet portion of the backward channels 66b for the fuel gas stream, hence those portions of the cell shall have a lower temperature. Accordingly, the vapor of the electrolyte having evaporated from the fuel cell 62 into the fuel gas and into the oxidizing gas while the gases are traveling through or below the forward channels 66a having a higher temperature is rapidly cooled in the outlet portion of the backward channels 66b and in the outlet portion of the oxidizing gas guide channels, the both portions having been cooled to have a lower temperature, and thus electrolyte is condensed at an extremely high rate into liquid drops in those portions. The thus-condensed phosphoric acid drops are then recovered.

Fig. 7 is a plan view illustrating still another preferred embodiment of a fuel cell of the fuel cell stack of the invention.

One difference between the embodiment of Fig. 7 and those illustrated hereinabove is in the arrangement of the coolant channel 23 in the cooling plate 20c.

The coolant channel 23 is so arranged that the part 23c downstream of the coolant inlet part 23a, at which the temperature of the cooling water being introduced into the coolant channel 23 is the lowest, is positioned in the outlet portion of the fuel gas backward channels 66b in a serpentine manner to be generally in the same width as that of the width (w) of the portion of the backward channels 66b and over the end portion 17b, that the part 23d downstream of the part 23c is positioned in the outlet portion of the oxidizing gas guide channels over the end portion 16b, and that the part further downstream of this part 23d is positioned at a predetermined pitch toward the coolant outlet 23b.

Having this coolant channel arrangement, the fuel cell is cooled effectively in the outlet portion of the fuel gas backward channels 66b and in the outlet portion of the oxidizing gas guide channels 68 , or in the portion overlapping with the end portion 16b, hence those portions of the cell shall have a lower temperature. Accordingly, the vapor of the electrolyte, phosphoric acid having evaporated from the cell into the fuel gas and into the oxidizing gas while the gases are traveling through or below the forward channels 66a having a higher temperature is rapidly cooled in the outlet portion of the backward channels 66b and in the outlet portion of the oxidizing gas guide channels, the both portions having been cooled to have a lower temperature, and thus electrolyte is condensed at an extremely high rate into liquid drops in those portions. The thus-condensed phosphoric acid drops are then recovered.

Fig. 8 is a plan view illustrating another preferred embodiment of a fuel cell of the fuel cell stack of the invention.

One difference between the embodiment of Fig. 8 and those illustrated hereinabove is in the piping arrangement of the coolant channel 24 in the cooling plate 20d.

The coolant channel 24 is so arranged that the part 24c downstream of the coolant inlet part 24a, at which the temperature of the cooling water being introduced into the coolant channel 24 is the lowest, is positioned in a serpentine manner to be generally in the outlet portion of the fuel gas forward channels 66a and in the inlet portion of the fuel gas backward channels 66b, while overlapping with the end portion 17a, that the part 24d downstream of the part 24c is positioned to overlap with the end portion 16b in the outlet portion of the oxidizing gas guide

channels, and that the part further downstream of this part 24d is positioned at a predetermined pitch toward the coolant outlet 24b.

Having this coolant channel arrangement, the fuel cell is cooled effectively in the outlet portion of the fuel gas forward channels 66a, in the inlet portion of the backward channels 66b, and in the outlet portion of the oxidizing gas guide channels, hence those portions of the cell shall have a lower temperature. Accordingly, the vapor of the electrolyte having evaporated from the cell into the fuel gas and into the oxidizing gas while the gases are traveling through or below the forward channels 66a having a higher temperature is rapidly cooled in the outlet portion of the fuel gas forward channels 66a, in the inlet portion of the backward channels 66b, and in the outlet portion of the oxidizing gas guide channels, those portions having been cooled to have a lower temperature, and thus electrolyte is condensed at an extremely high rate into liquid drops in those portions. The thus-condensed phosphoric acid drops are then recovered.

If desired, the arrangement of the coolant channel 24 of this embodiment of Fig. 8 may be so modified that the part 24e, which is downstream of the part 24c and runs oppositely to the part 24c toward the part 24d, is positioned to overlap with an area beyond the end portion 17a, or that is, with an area within the power-generating zone.

Fig. 9 is a plan view illustrating another preferred embodiment of a fuel cell of the fuel cell stack of the invention.

One difference between the embodiment of Fig. 9 and those illustrated hereinabove is in the arrangement of the coolant channel 25 in the cooling plate 20e.

The coolant channel 25 is so arranged that the part 25c downstream of the coolant inlet part 25a, at which the temperature of the cooling water being introduced into the coolant channel 25 is the lowest, is positioned in a serpentine manner to be generally in the outlet portion of the oxidizing gas guide channels while overlapping with the end portion 16b, and that the part further downstream of this part 25c is positioned at a predetermined pitch toward the coolant outlet 25b.

Having this coolant channel arrangement, the fuel cell is cooled effectively in the outlet portion of the oxidizing gas guide channels to thereby make that portion have a lower temperature. Accordingly, the vapor of the electrolyte having evaporated from the cell into the oxidizing gas while the gas is traveling below the

fuel gas forward channels 66a having a higher temperature is rapidly cooled in that outlet portion of the oxidizing gas guide channels to have a lower temperature, and thus electrolyte is condensed at an extremely high rate into liquid drops in that portion. The thus-condensed phosphoric acid drops are then recovered.

Fig. 10 is a plan view illustrating another preferred embodiment of a fuel cell of the fuel cell stack of the invention.

Some differences between the embodiment of Fig. 10 and those illustrated hereinabove in the channeling arrangement of the fuel gas guide channels and in the channeling arrangement of the coolant channel 26 in the cooling plate 20f.

The fuel gas guide channels are so arranged that the fuel gas to be passed therethrough shall turn twice at the fuel gas manifolds 10 and 11 and travel three times through the guide channels 66 in opposite directions. Further, the coolant channel 26 is so arranged that the part 26c downstream of the coolant inlet part 26a, at which the temperature of the cooling water being introduced into the coolant channel 26 is the lowest, is positioned in a serpentine manner to be generally in the outlet portion of the oxidizing gas guide channels while overlapping with the end portion 16b, and that the part further downstream of this part 26c is positioned at a predetermined pitch toward the coolant outlet 26b.

Having these fuel gas-channeling arrangement and coolant channel arrangement, the cell is cooled effectively in the outlet portion of the oxidizing gas guide channels to thereby make that portion have a lower temperature. Accordingly, the vapor of the electrolyte having evaporated from the cell into the oxidizing gas while the gas is traveling below the portions of the fuel gas channels 66a and 66b having a higher temperature is rapidly cooled in the outlet portion of the oxidizing gas guide channels to have a lower temperature, and thus electrolyte is condensed at an extremely high rate into liquid drops in that portion. The thus-condensed phosphoric acid drops are then recovered.

Fig. 11 is a plan view illustrating the another embodiment of a fuel cell of the fuel cell stack of the invention.

Some differences between the embodiment of Fig. 11 and those illustrated hereinabove are in the channeling arrangement of the oxidizing gas guide channels and in the channeling arrangement of the coolant channel 27 in the cooling plate 20g.

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The oxidizing gas guide channels are so arranged that there are a forward group of channels 31a and a backward group of channels 31b through which the oxidizing gas shall travel in opposite directions, like the arrangement of the fuel gas guide channels. Moreover the coolant channel 27 is so arranged that the part 27c downstream of the coolant inlet part 27a, at which the temperature of the cooling water being introduced into the coolant channel 27 is the lowest, is positioned in a serpentine manner to be generally in the inlet portion of the fuel gas backward channels 66b nearly in the same width as the width of that inlet portion of the backward channels 66b, while overlapping with the end portion 17a, that the part 27d downstream of the part 27c is positioned in a serpentine manner to be generally in the outlet portion of the oxidizing gas backward channels 31b nearly in the same width as the width (w) of that outlet portion of the backward channels 31b, while overlapping with the end portion 16b, and that the part further downstream of this part 27d is positioned at a predetermined pitch toward the coolant outlet 27b.

Having these oxidizing gas-channeling arrangement and coolant channel arrangement, the fuel cell is cooled effectively in the inlet portion of the fuel gas backward channels 66b and in the outlet portion of the oxidizing gas backward channels 31b to thereby make those portions have a lower temperature. Accordingly, the vapor of the electrolyte having evaporated from the cell into the fuel gas and into the oxidizing gas while the gases are traveling through the forward channels 66a and the forward channels 31a, respectively, all having a higher temperature are rapidly cooled in that inlet portion of the backward channels 66b and in that outlet portion of the backward channels 31b, both portions being cooled to have a lower temperature, and thus electrolyte is condensed at an extremely high rate into liquid drops in those portions. The thus-condensed phosphoric acid drops are then recovered.

In this embodiment, the part 27c downstream of the coolant inlet part 27a, at which the temperature of the cooling water being introduced into the coolant channel 27 is the lowest, is positioned in the inlet portion of the fuel gas backward channels 66b, and the part 27d downstream of the part 27c is positioned in the outlet portion of the oxidizing gas backward channels 31b. This channel arrangement may be modified in order that the coolant channel part 27c downstream of the coolant inlet part 27a, at which the temperature of the cooling

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water being introduced into the coolant channel 27 is the lowest, is positioned to be in the outlet portion of the oxidizing gas backward channels 31b, and that the part 27d downstream of the part 27c is positioned to be in the inlet portion of the fuel gas backward channels 66b.

The embodiments illustrated hereinabove have a plurality of forward and backward channels for fuel gas traveling therethrough in opposite directions, or a plurality of guide channels for oxidizing gas traveling therethrough in the same direction in one channel but in opposite directions in other channels.

Fig. 12 is a plan view illustrating another preferred of a fuel cell of the fuel cell stack of the invention.

Some differences between the embodiment of Fig. 12 and those illustrated hereinabove are in the channeling arrangement of the oxidizing gas guide channels and in the channeling arrangement of the coolant channel 27 in the cooling plate 20g.

The oxidizing gas guide channels are so arranged that there are a forward group of channels 31a and a backward group of channels 31b through which the oxidizing gas shall travel in opposite directions, like the arrangement of the fuel gas guide channels. Moreover, the coolant channel 27 is so arranged that the part 27c downstream of the coolant inlet part 27a, at which the temperature of the cooling water being introduced into the coolant channel 27 is the lowest, is positioned in a serpentine manner to be generally in the outlet portion of the fuel gas backward channels 66b nearly in the same width as the width of that outlet portion of the backward channels 66b, while overlapping with the end portion 17a, that the part 27d downstream of the part 27c is positioned in the outlet portion of the oxidizing gas backward channels 31b nearly in the same width as the width (w) of that outlet portion of the backward channels 31b, while overlapping with the end portion 16b, and that the part further downstream of this part 27d is positioned at a predetermined pitch toward the coolant outlet 27b.

Having these oxidizing gas-channeling arrangement and coolant channeling arrangement, the fuel cell is cooled effectively in the outlet portion of the fuel gas backward channels 66b and in the outlet portion of the oxidizing gas backward channels 31b to thereby make those portions have a lower temperature. Accordingly, the vapor of the electrolyte having evaporated from the cell into the fuel gas and into the oxidizing gas while the gases are traveling through the

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forward channels 66a and the forward channels 31a, respectively, all having a higher temperature are rapidly cooled in that outlet portion of the backward channels 66b and in that outlet portion of the backward channels 31b, both portions being cooled to have a lower temperature, and thus electrolyte is condensed at an extremely high rate into liquid drops in those portions. The thus-condensed phosphoric acid drops are then recovered.

In this embodiment, the part 27c downstream of the coolant inlet part 27a, at which the temperature of the cooling water being introduced into the coolant channel 27 is the lowest, is positioned in the outlet portion of the fuel gas backward channels 66b, and the part 27d downstream of the part 27c is positioned in the outlet portion of the oxidizing gas backward channels 31b. This channeling arrangement may be modified in order that the coolant channel part 27c downstream of the coolant inlet part 27a, at which the temperature of the cooling water being introduced into the coolant channel 27 is the lowest, is positioned to be in the outlet portion of the oxidizing gas backward channels 31b, and that the part 27d downstream of the part 27c is positioned to be in the outlet portion of the fuel gas backward channels 66b.

In the embodiments illustrated hereinabove, phosphoric acid is used as the electrolyte. Any other various electrolytes that are liquid at the operation temperatures in the fuel cell stack of the invention may also be used.

The present invention may apply to the recovery of water in the exit gas streams of solid polymer electrolyte fuel cells. One example of a solid polymer electrolyte fuel cell 62a is shown in Fig. 13, in which a polymer electrolyte membrane 41 is sandwiched between a porous anode 42 and a porous cathode 43 both having a smaller perimeter than the membrane 41, 44, 45 are disposed around those anode 42 and cathode 43, and a fuel guide plate 46 is disposed adjacent to the anode 42 while an oxidizing agent guide plate 47 adjacent to the cathode 43. In operation, fuel gas is introduced into the fuel gas channels 48 of the fuel guide plate 46, along with water that acts as a humidification agent and also as a coolant, while oxidizing gas is introduced into the oxidizing gas channels 49 of the oxidizing agent guide plate 47.

In this embodiment, water is necessary for wetting the polymer electrolyte membrane 41, but it may evaporate with the increase in the temperature of the cell 62a, and passes through the fuel gas channels 48 and the oxidizing gas channels

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49 to be discharged outside the cell. However, a problem is that the water loss from the membrane in the cell decreases the cell efficiency.

To reduce the water loss, the present invention provides for the portion around the gas guide channels of the fuel guide plate 46 and the oxidizing agent guide plate 47 be made of a porous material, and coolant channels 50 for cooling the downstream portion of the fuel gas channels 48 and coolant channels 51 for cooling the downstream portion of the oxidizing gas channels 49 are provided. This coolant is introduced into those coolant channels to thereby condense and recover the vapor of water that is traveling through those fuel gas channels 48 and oxidizing gas channels 49 and going outside therethrough.

In the solid polymer electrolyte fuel cell of the present invention, the water vapor existing in the fuel gas moves from the anode 42 to the cathode 43 via the membrane 41 by electrochemical action. Therefore, the cell requires the recovery of the water vapor having entered the oxidizing gas from the cathode 43.

Thus, there are provided coolant channels 50 for cooling the downstream portion of the fuel gas channels 48 and coolant channels 51 for cooling the downstream portion of the oxidizing gas channels 49. A coolant is introduced into those coolant channels to thereby condense and recover the vapor of water that is traveling through the fuel gas channels 48 and oxidizing gas channels 49 and going outside the cell stack. This coolant-channeling arrangement improves the efficiency of the solid polymer electrolyte fuel cell.

There are provided coolant channels in the fuel guide plate 46 and in the oxidizing agent guide plate 47, with which the downstream portions of the fuel gas channels 48 and the oxidizing gas channels 49 are cooled to thereby condense and recover the water vapor existing in the fuel gas and the oxidizing gas. Cooling plates may be interposed in the stack of those fuel cells without providing the coolant channels in the fuel guide plate 46 and the oxidizing agent guide plate 47 and the cooling plates may be formed to have coolant channels therein. In this embodiment, the downstream portions of the fuel gas channels 48 and the oxidizing gas channels 49 may be cooled with the coolant traveling through those coolant channels.

As has been described in detail hereinabove, the present invention provides a fuel cell stack in which the electrolyte and other condensable substances having evaporated into fuel gas or oxidizing gas can be effectively condensed and

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recovered without decreasing the power-generating capacity of the fuel cells, and the operable life and even the efficiency of the fuel cells constituting the stack can be prolonged and improved.

While the invention has been described in detail and with reference to specific embodiments thereof, it will be apparent to one skilled in the art that various changes and modifications can be made therein without departing from the spirit and scope thereof. Accordingly, reference should be made primarily to the following claims rather than the foregoing description to determine the scope of the present invention.

Claims

1. A fuel cell assembly comprising a plurality of fuel cells, each cell having a pair of porous electrodes with an electrolyte layer being sandwiched therebetween and a pair of gas guide means disposed adjacent to and over said pair of porous electrodes for passing fuel gas and oxidizing gas therethrough in a direction perpendicular to each other, and a cooling means for each cell for cooling a part of a nonelectrochemical reaction zone being positioned outside an electrochemical reaction zone whereby said electrochemical reaction zone is defined by the range of said pair of gas guide means overlapping with each other in the stacking direction to provide for the temperature of said part of said nonelectrochemical reaction zone lower than that of said electrochemical reaction zone thereby condensing at least a part of a condensable substance from the gases being passed through said pair of gas guide means into the fuel cells.

2. The fuel cell assembly of claim 1, wherein said cooling means is for cooling the portion nearer to a gas outlet portion of at least one gas guide means within the nonelectrochemical reaction zone to thereby make said nearer portion have a lower temperature.

3. The fuel cell assembly according to claim 2, wherein said cooling means is provided with a cooling plate having a coolant channel therein, through which a coolant is passed.

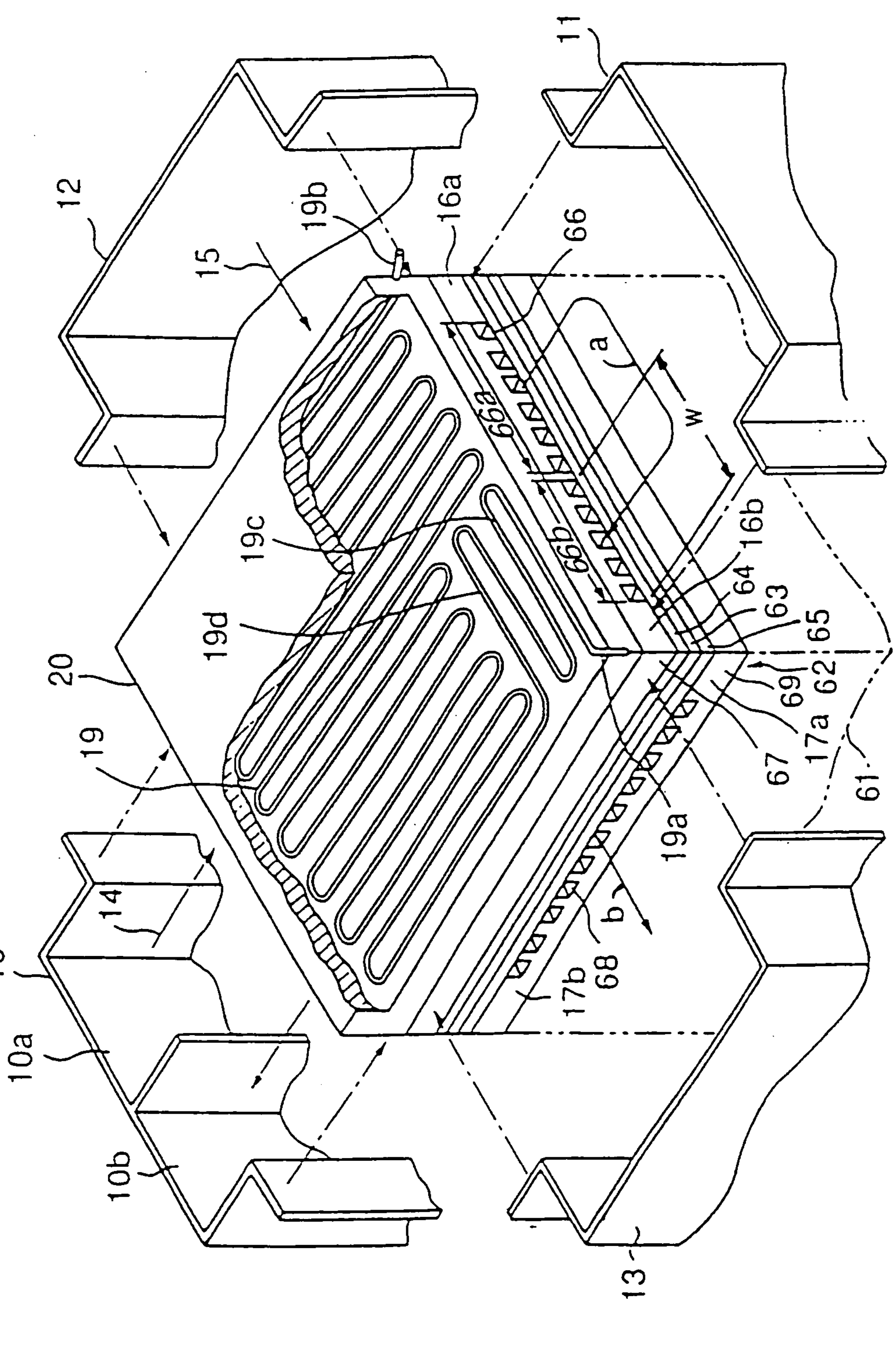
4. The fuel cell assembly according to claim 3, wherein the condensable substance is electrolyte vapor.

5. The fuel cell assembly according to claim 3, wherein the condensable substance is water vapor.

6. A fuel cell assembly, which comprises a stack of a plurality of fuel cells, each cell having a pair of porous electrodes with an electrolyte layer being sandwiched therebetween and a pair of gas guide means disposed adjacent to and

over said pair of porous electrodes for passing fuel gas and oxidizing gas therethrough in a direction perpendicular to each other, at least one gas guide means being so constructed as to have at least two or more forward and backward channel sections directed to the opposite sides, through which said gas travels forward along said porous electrodes and then backward along them, and a cooling means for each cell for cooling at least a gas inlet portion of said backward channel section of said gas guide means within a nongenerating zone being positioned outside a generating zone to be defined by the range of said pair of gas guide means overlapping with each other in the stacking direction to thereby provide for the temperature of said gas inlet portion lower than that of said forward channel section in said generating zone thereby condensing and recovering at least a part a condensable substance from the gases being guided by the gas guide means through the cells.

FIG.1



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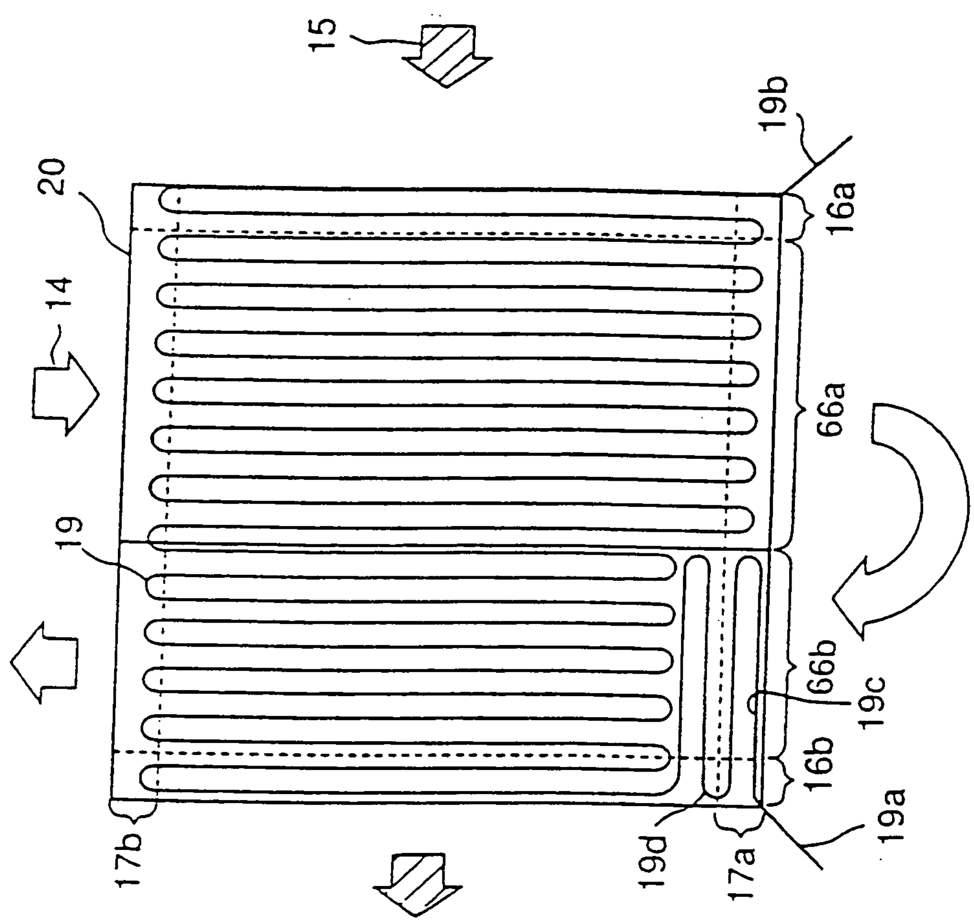

FIG.2

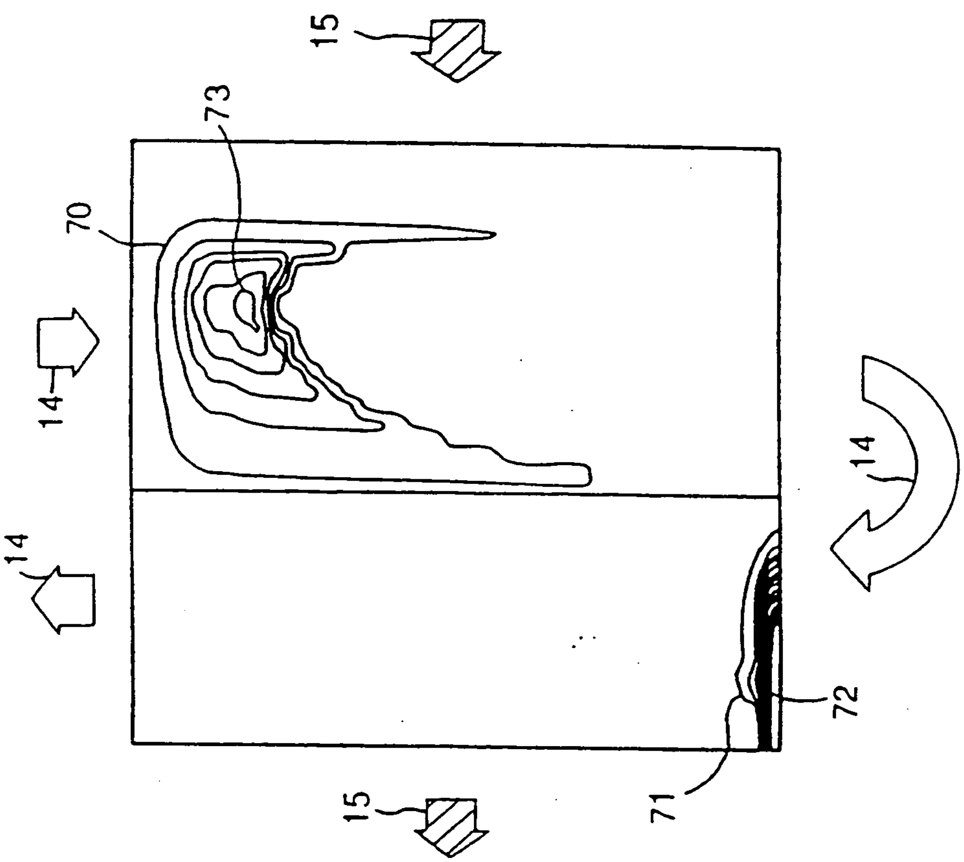

FIG.3

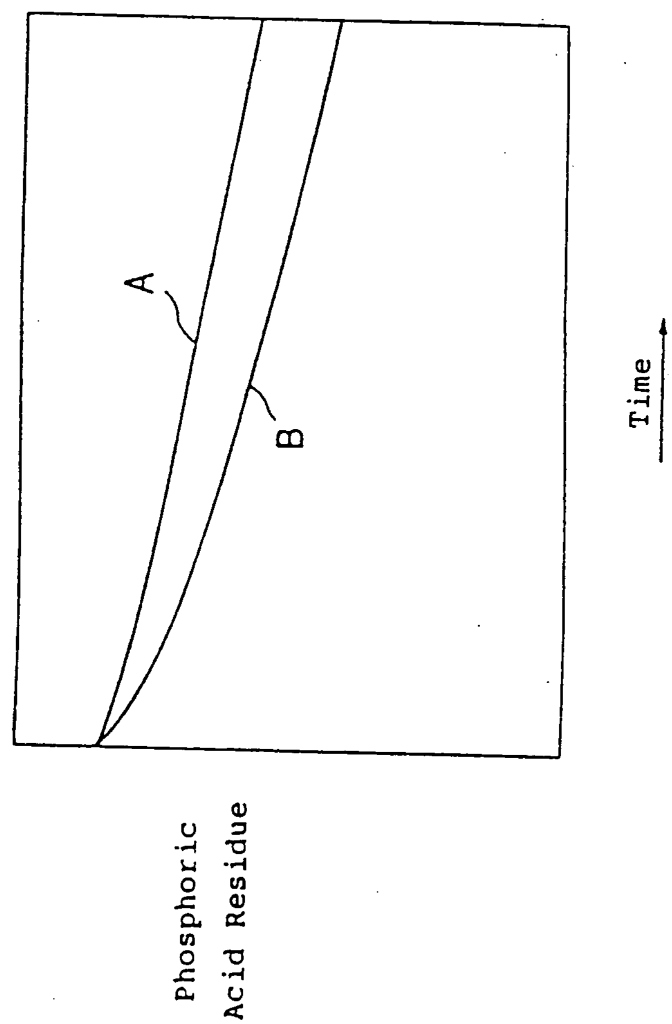

FIG.4

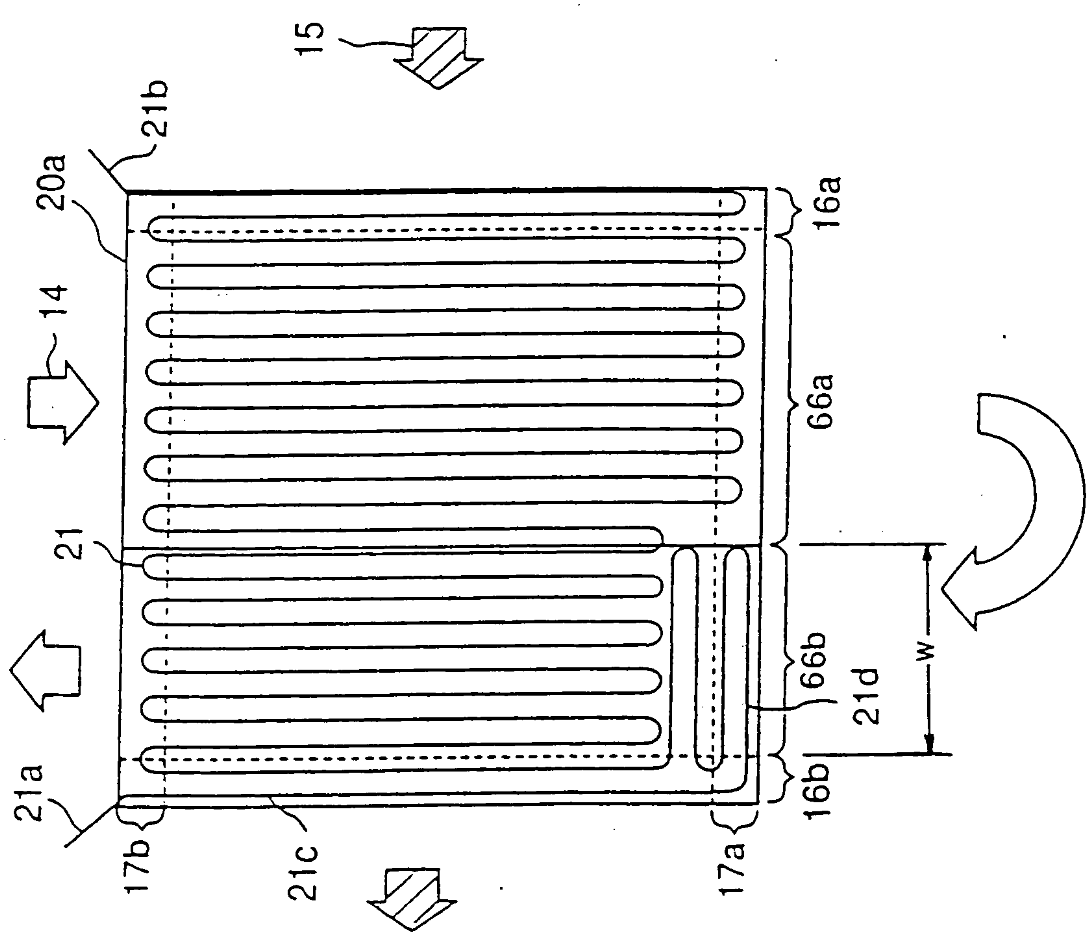

FIG.5

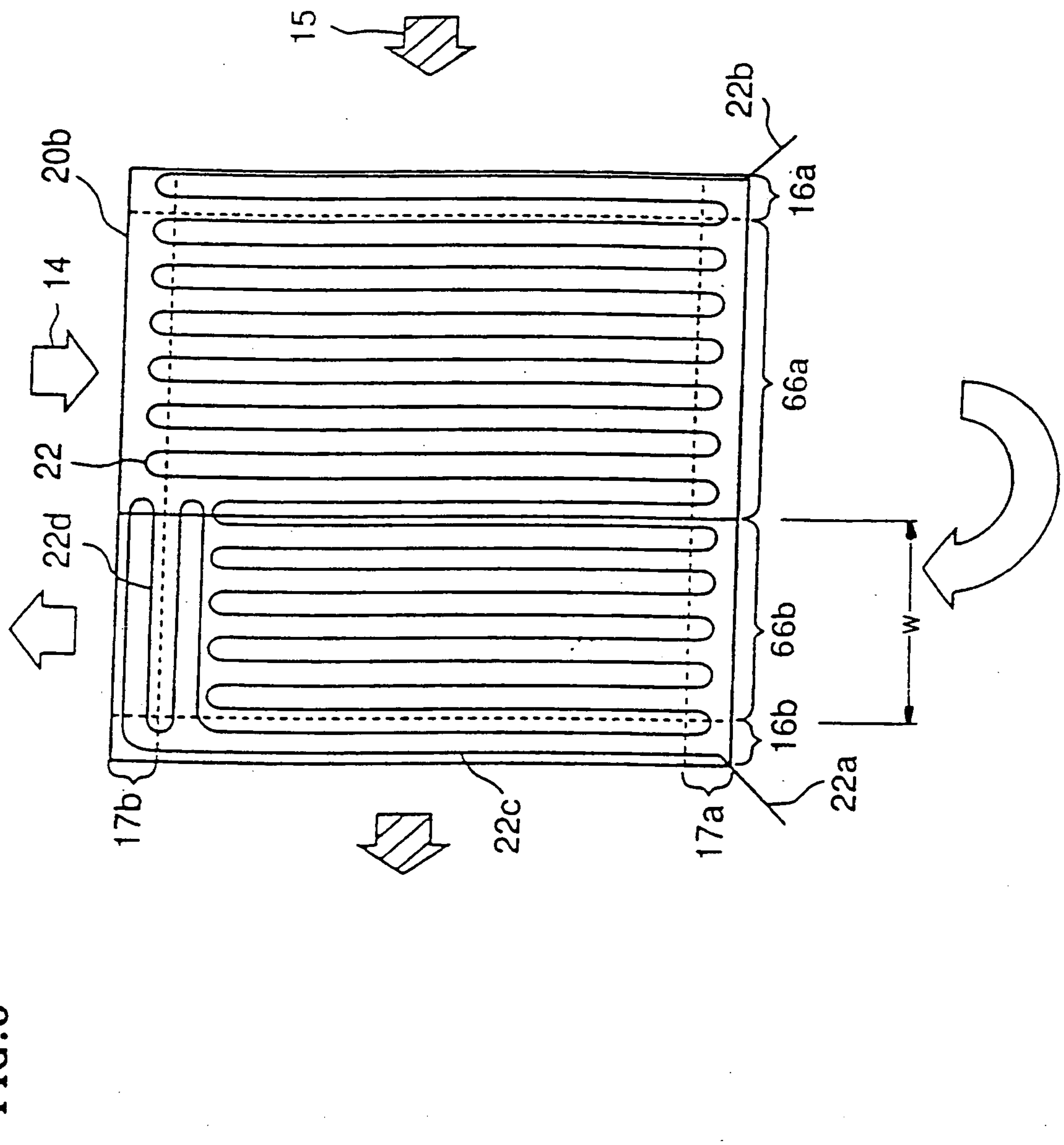

FIG.6

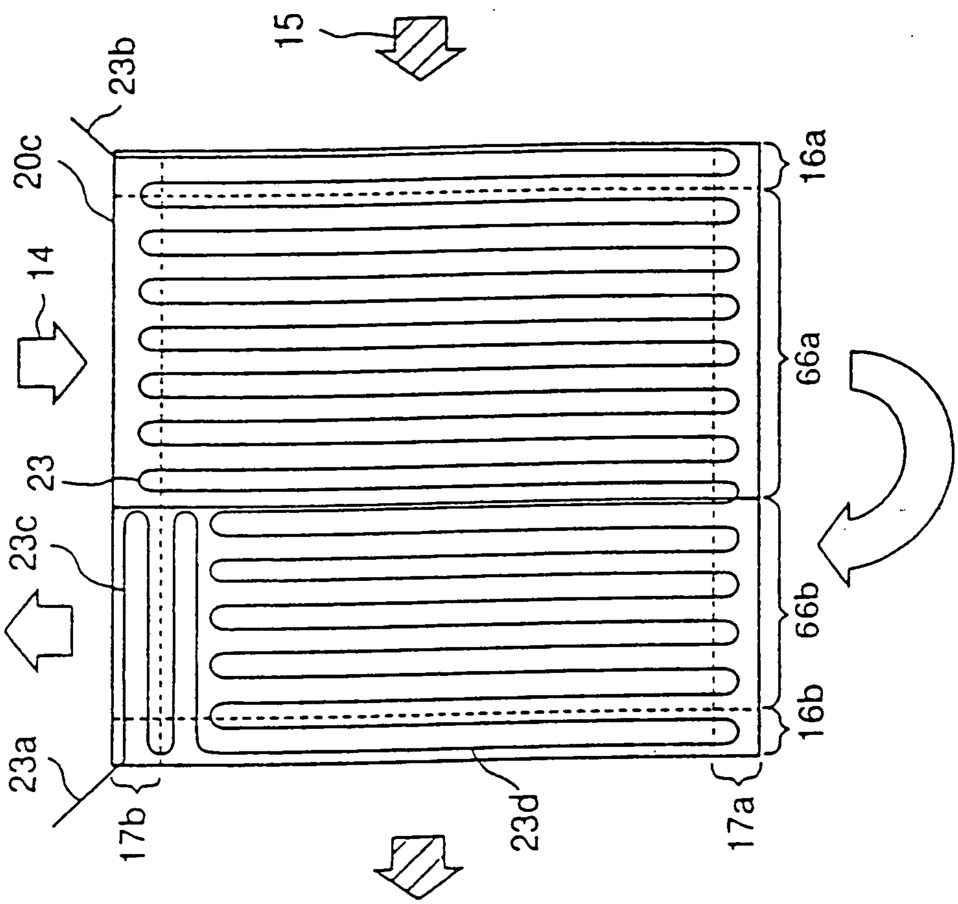

FIG.7

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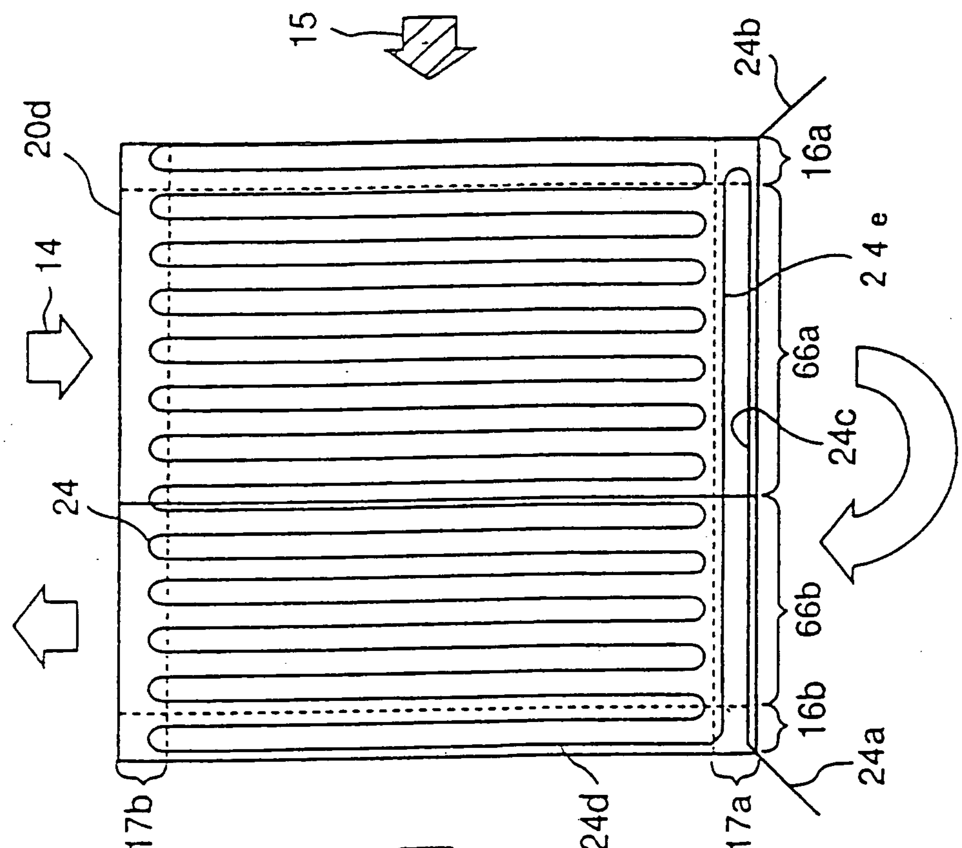

FIG.8

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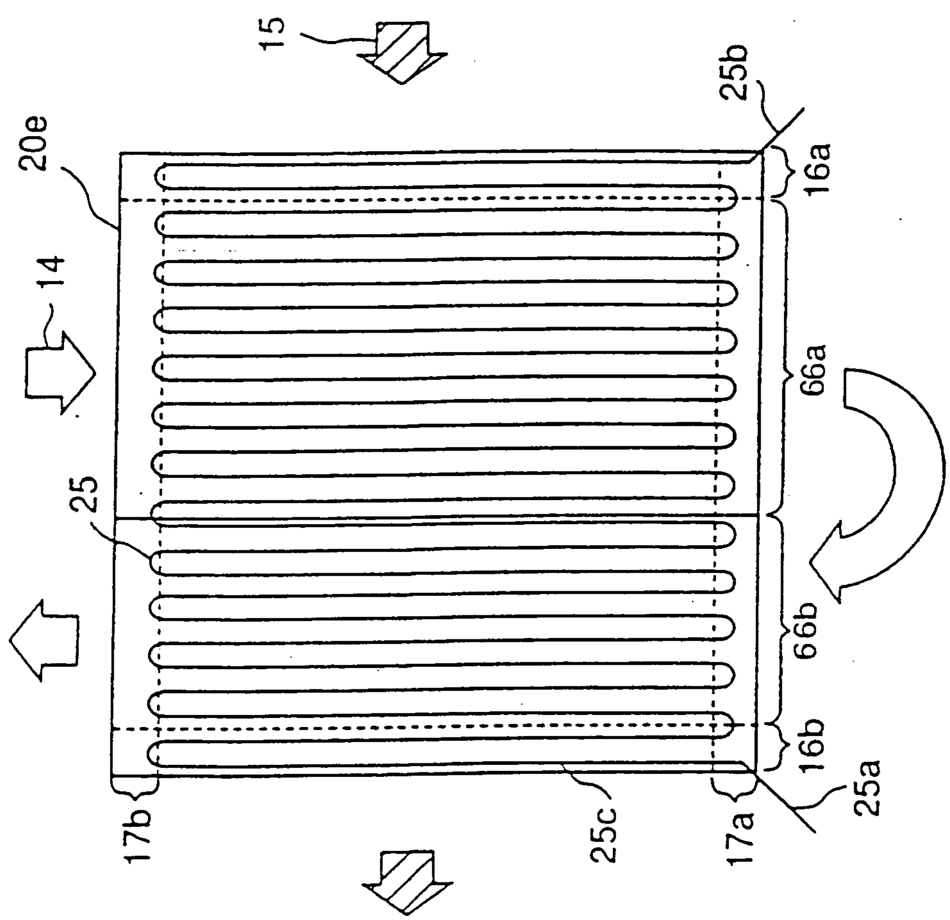

FIG.9

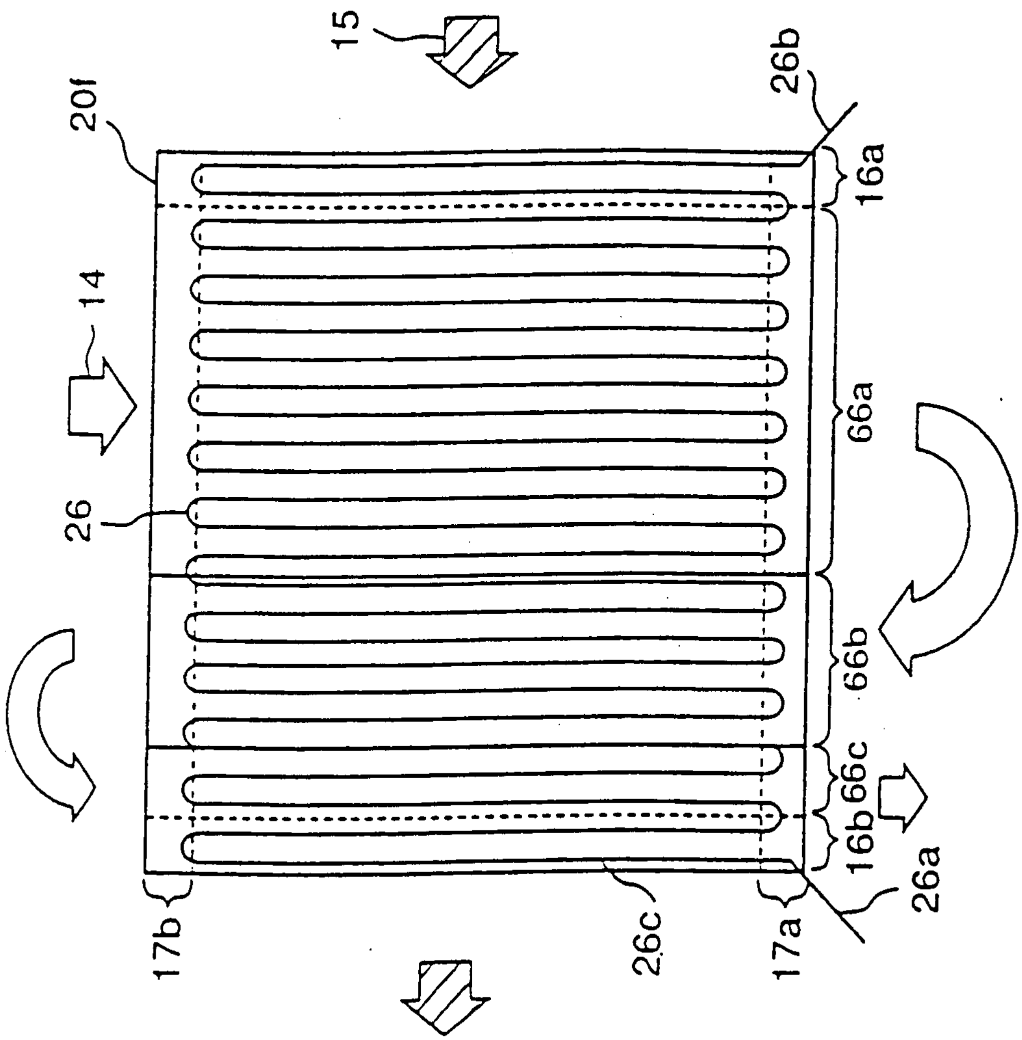

FIG.10

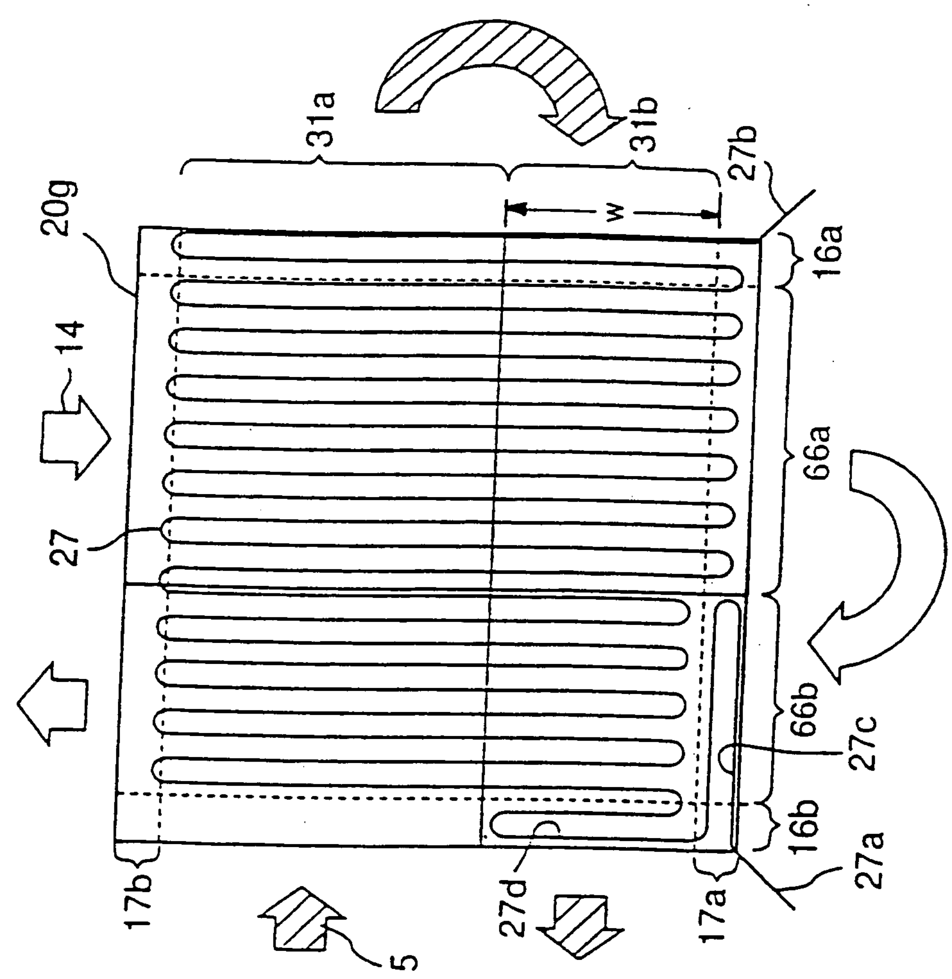

FIG.11

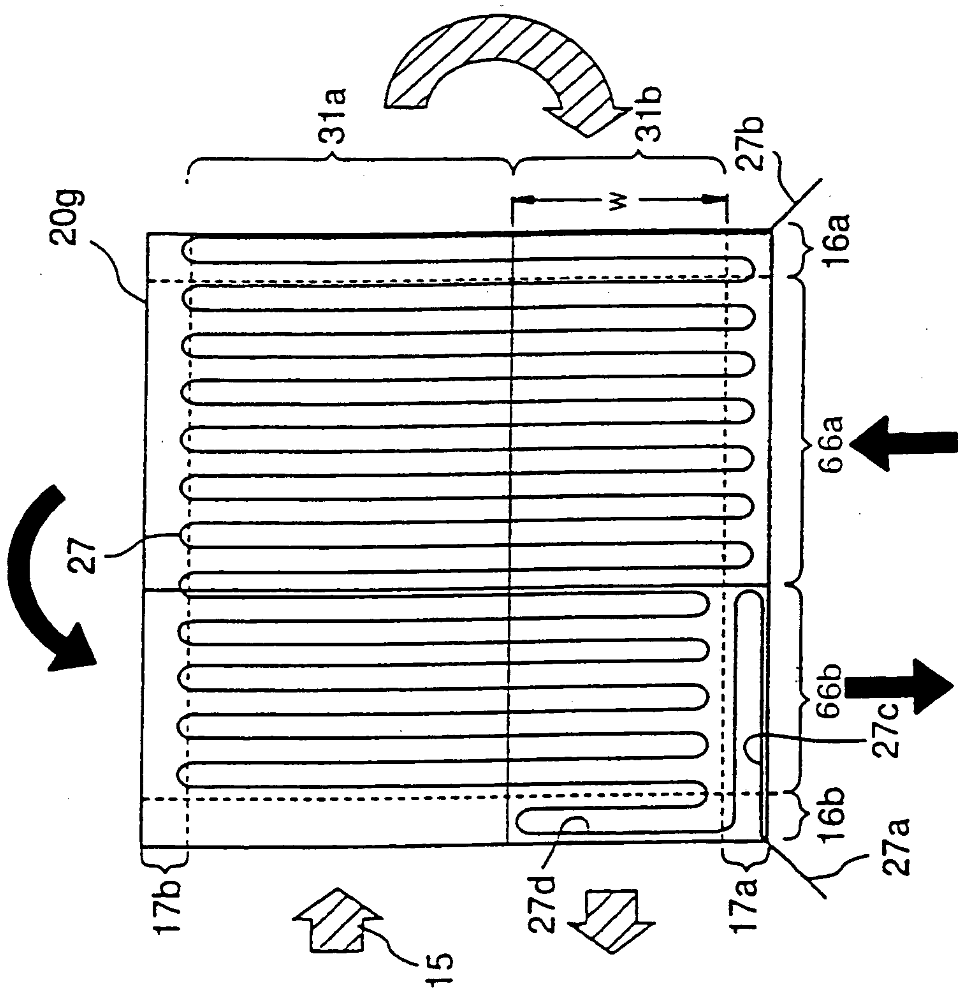

FIG.12

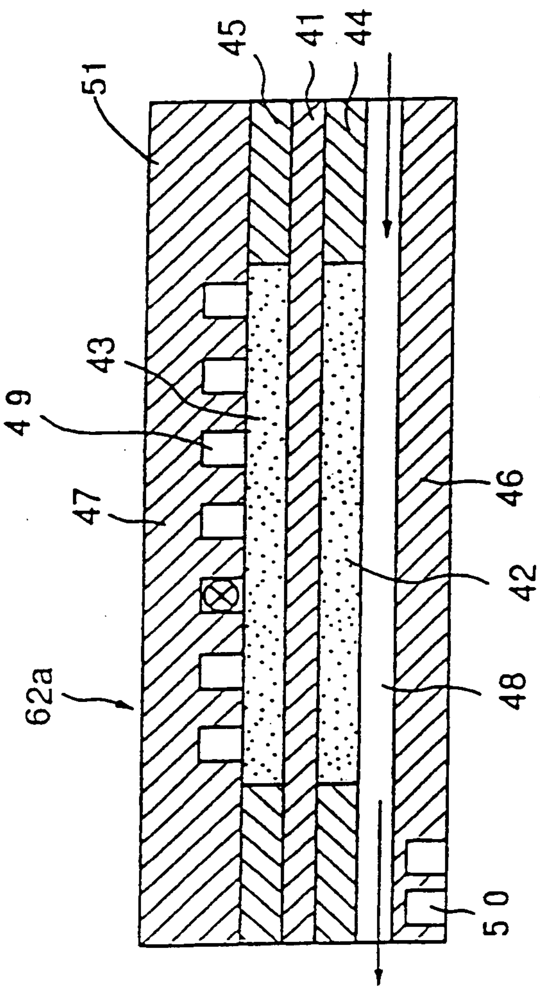

FIG.13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/30262

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H01M 8/02, 8/08
US CL :429/26, 39

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 429/26, 34, 38, 39

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Derwent, JPAB, EPAB
search terms: fuel cell + cooling plate

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 8-31437 A (TOSHIBA CORP) 02 February 1996, see Derwent, JPAB abstracts; the Figures.	1-6
X	US 4,324,844 A (KOTHMANN et al) 13 April 1982, see the Figures; col. 3, line 44.	1-5
A	US 4,973,530 A (VANDERBORGH et al) 27 November 1990, see Figs. 2A-B, 4A-B, 6A-C; and col. 6, line 66-col. 7, line 17.	1-3, 5, 6
X	US 4,945,010 A (KAUFMAN et al) 31 July 1990, see Figs. 1-4a; col. 6, lines 15-28.	1-5
A	US 4,599,282 A (HIROTA et al) 08 July 1986, see the Figures.	1-6

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 FEBRUARY 2000	17 MAR 2000

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/30262

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 7-183036 A (MITSUBISHI ELECTRIC CORP) 21 July 1995, see Figures 1, 2, 11, 12; JPAB and Derwent abstracts.	1-6